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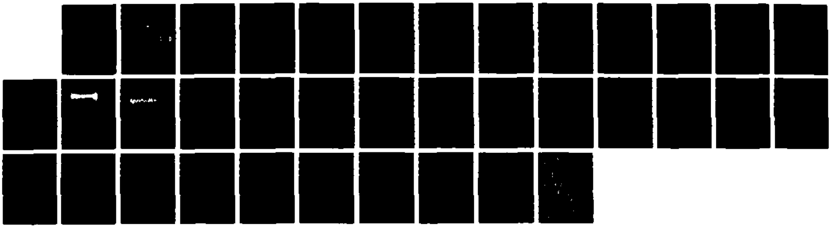

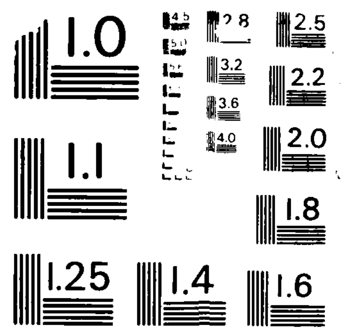
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The second International Comparison of Absolute Gravimeters was carried out in Sevres, France, June-July 1985. During this intercomparison, six instruments from five countries occupied pre-assigned sites at the Bureau of Weights and Measures (BIPM). The objective was to learn of possible systematic errors associated with these instruments and also to learn of the different approaches used by other experimenters in the field of absolute gravimetry.

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RESULTS OF THE SECOND INTERNATIONAL COMPARISON OF ABSOLUTE GRAVIMETERS IN SEVRES 1985

Editors: Yu. Boulanger[1], J. Faller[2], E. Groten[3]

Coauthors: G. Arnautow[4], M. Becker[3], H. Beetz[5], R. Beruff[6], L.Cannizzo[7], G. Cerutti[7], Feng-Youg-Yuan[8], Guo Yuguang[8], L.A. Haller[9], H. Hanada[10], W. Hollander[2], Huang Da-Lun[8], E. Kalish[4], I. Marson[11], T. Niebauer[1], C. Poitevin[12], B. Richter[5], R. Röder[13], A. Sakuma[14], R. Sands[15], C. Sasagawa[16], S. Schleglov[1], M. Schnüll[13], W. Spita[6], Yu. Stus[4], W. Tarasiuk[4], G. Wenzel[13], Zhang Guang-Yuan[8], Zhou Juing-Hua[8], Zhou Kungen[12], M. Zumberge[16]

1 Institute of Physics of the Earth, Academy of Sciences of the USSR, Moscow 123810, USSR (Absolute Gravimeter GABL)
2 Joint Institute for Laboratory Astrophysics, University of Colorado, Boulder, Colorado 80309-0440, USA (Absolute Gravimeter USA 1)
3 Institut für Physikalische Geodäsie, University of Darmstadt, Fed. Rep. of Germany (Gravimeters G258 and D38F)
4 Institute of Automatics and Electrometry, Siberian Branch of Academy of Sciences of the USSR, Novosibirsk 630090, USSR (Absolute Gravimeter GABL)
5 Institut für Angewandte Geodäsie, Frankfurt, Fed. Rep. of Germany (Gravimeters G563 and D21)
6 Defense Mapping Agency HTC, 20315 Washington D.C., USA (Gravimeters G131 and D79)
7 Instituto di Metrologia "G. Colonnetti", 10135 Torino, Italy (Italien Absolute Gravimeter)
8 National Institute of Metrology, Beijing, China (Chinese Absolute Gravimeter)
9 Land Survey of Sweden, S-801 12 Gävle, Sweden (Gravimeters G290 and G54)
10 International Latitude Service, Mizusawa, Japan (Gravimeter G305)
11 University of Triest, 34123 Trieste, Italy (Italien Absolute Gravimeter)
12 Observatoire Royal De Belgique, B-1200 Bruxelles, Belgique (Gravimeters G487F and D31F)
13 Institut für Erdmessung, University Hannover, Fed. Rep. of Germany, (Gravimeters G298F, G709F and D8F)
14 Bureau International des Poids et Mesures, Pavillon de Breteuil, Sevres, France (BIPM Absolute Gravimeter)
15 Air Force Geophysics Laboratory, Hanscom AFB, Massachusetts 01731, USA
16 Scripps Institution of Oceanography, A-025, University of California, La Jolla, California 92093, USA (Absolute Gravimeter USA 2)

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Following the recommendation of the International Association of Geodesy, the First Comparison of Absolute Gravimeters was carried out in 1981 (Sevres, 1981).[1,2] One result that came out of that highly successful intercomparison was the confirmation of certain previously suspected systematic errors. At the General Assembly of IAG (Hamburg, 1983), with the hope of a somewhat greater participation and with a view to establishing a new first-order world gravimetric network, a resolution was adopted to organize in 1984 a Second International Comparison of Absolute Gravimeters. However, as several instruments were either not ready or unavailable for joint operations at the initially fixed date, the comparison was postponed to June-July 1985.

At the kind invitation of the Bureau International des Poids et Mesures, the comparison was again conducted in Sevres at the main laboratory building of the BIPM. The preparation and the comparison procedure was entrusted to Prof. Yu. Boulanger, Chairman of SSG 3.86. (This special study group's charge is the evaluation of absolute gravity measurements.)

The instruments that were used came from five different countries: China, France, Italy, USA (two instruments), and the USSR. All six of these instruments employ ballistic methods and utilize laser interferometry to measure position as a function of time. Two of them (BIPM and Italian) employ symmetrical rise-and-fall methods, while the others use direct free fall. Four (BIPM, Italian, Soviet, and the JILA-USA instrument) utilize some form of long-period isolation device to help reduce the drop-to-drop scatter. The IGPP-USA instrument uses a short (~1 sec) period isolation device, and the Chinese instrument does not (yet) utilize any form of mechanical isolation.

The intercomparison of all of the absolute instruments was made by transferring each of the individual measurements to a single benchmark set on the pillar at Site A. To do this, a micro-gravity net (Fig. 1) of gravity

differences was established using relative gravimeters. The vertical gravity gradients were also measured at all of the sites on which absolute gravimeters were installed. The sites of absolute gravimeter installations were fitted precisely with the marks over which the absolute measurements were taken.

Prof. E. Groten, Chairman of SSG 3.85 (This study group is concerned with the comparison of high-precision gravimeter techniques.), kindly agreed to organize and carry out the relative measurements and to process the results obtained. Table 1[3] shows vertical gradients W_{zz} assumed at the reduction to the pillar surface of g_o determined at the effective height H_o. Table 2 gives reductions to Site A and their errors.[3]

Altogether more than 1200 gravimeter readings were taken by 14 LaCoste Romberg gravimeters. The average accuracies as obtained in the least-squares adjustment are ±0.8 μgal for the gradients and ±0.7 μgal for the gravity differences. Questions of precision and accuracy of the relative gravimetry are discussed in Ref. 3 in more detail. With respect to the accuracy of the absolute apparatuses to be described below, the gravity differences of the combined adjustment of all instruments can be regarded as true reference values.

All absolute measurements were taken between June 28 and July 9, 1985, with a break from July 3 to 8, during which period the relative measurements were performed.

Table 3 gives the assigned errors for the absolute measurements. Column 1 lists the sources of these errors; the other columns give their values obtained on the engineering-physical basis. The similarity of errors for all instruments should be noted.

The complete error for g,

$$M = \pm \left(M_o^2 + \Sigma m^2\right)^{1/2}$$

fell within the range of ±5.6 μgal to ±7.8 μgal. The Chinese instrument is an exception (±13.8 μgal); it has a large random error of ±11.2 μgal (attributable to its present lack of a mechanical isolating system).

Table 4 presents a summary of all measurements taken by the absolute gravimeters. Appendices 1, 2, 3, and 4 give more detailed data, i.e., results of measurements by individual falls and by series of falls. Results of measurements with the JILA instrument at Site A5 are represented by two histograms (Figs. 2 and 3). No detailed results of measurements performed by the Sakuma instrument were presented.

Corrections for tidal gravity variations were introduced into all of the absolute measurements; they were taken from the tables kindly supplied by Prof. Sakuma to all participants. This provided a uniform system of tidal corrections for all the instruments to use during this intercomparison. These corrections, incidently, were found to have a systematic discrepancy in amplitude of between 2 and 4 μgal on comparing them with the tidal corrections normally used with the various instruments.

The Honkasalo correction and the correction for polar motion were not introduced, whereas (common) corrections for the atmospheric mass attraction were introduced to all measurements.

Reduction to the pillar surface of g measured at an effective height, H_o, was calculated by the formula:

$$\Delta g_{W_{zz}} = W_{zz} H_o \quad .$$

Gradients, W_{zz}, and their errors are shown in Table 1.

Table 5 gives results of all absolute determinations made during the calibration of gravimeters and adjusted to Site A at the pillar surface. The results of the intercomparison were rather surprising (Table 5). The results tend to fall into three groups. The maximum discrepancy between instruments reached 37.7 ± 9.4 μgal, an amount which cannot be explained simply by an accumulation of the individual quoted errors. Further, given the grouping, no simple correspondence with the particular method of measurement is evident.

One can only conclude from these data that in addition to the stated mean square errors of about ±5 to ±8 μgal for 5 of the 6 individual instruments, some or all have an as yet unrecognized systematic error source that could be as large, in the extreme case, as some tens of μgals. It should be noted that our analysis of the measurements does not single out for preference any one group of instruments. Therefore, without the benefit of additional studies and/or further intercomparisons, and noting the general similarity of instruments, the present accuracy of an absolute gravity determination by any one instrument could be in doubt (mean square error) by as much as ±15 μgal.

This result poses an important question in regard to establishing a new first-order global gravity network. If a mean error of ±10 μgal is required for this net (as has been stated many times) and absolute gravimeters are to be (necessarily) utilized, then the multiple instrument method of measurements would seem to be required. Under this approach, each site of this net would need to be occupied by no less than three different absolute gravimeters. The difficult question is: "Which three?"

There is, however, another possibility to be considered. One would expect the relative precision of measurement of an absolute gravimeter to exceed its absolute accuracy — at least over time periods during which major modifications and/or component changes have not occurred. And indeed, there is

an excellent correlation of the Δg results between pillars A3 and A6 as measured by the GABL absolute gravimeter and the relative instruments. From absolute measurements, this difference was found to be 679.4 μgal; but from relative measurements it was 679.9 ± 0.8 μgal. This serves to corroborate this expectation: the measurement precision of an absolute instrument is higher than its measurement accuracy. When one is using absolute gravimeters to look for slow changes of the gravity field of the Earth with time, this fact can be expected to be helpful. Given the long time intervals (one year or longer) required to look for these changes, this increase in precision may not in practice be fully realizable unless one is conducting differential measurements. In using absolute gravimeters to establish a global gravity network, however, one would expect to be able to take advantage of this increase in precision. In that case, one is making (in part) differential measurements and the time intervals between absolute measurements at the various sites would be short.

The discrepancies between the gravity differences of the relative gravimeters to site A3 in the 1985 and the 1985 campaigns can be associated with the eccentric position of the gravity meters in the 1981 campaign. If a suitable correction is applied, the differences are reduced significantly, see Table 2a.

The situation with the gradient on A3 is more complicated as can be seen in Table 1a. Even if the measurements in 1981 were affected by the eccentric measurements, there has been a rather large increase in the gradient since 1980 or even since 1984 of more than 10 μgal/m.

It is interesting to compare the results of absolute determinations made in 1981 and 1985 on pillars A5 and A6, because on these pillars the values of W_{zz} and the differences of Δg (A-A5) and Δg (A-A6) were found in both cases to

be very close. On pillar A5 the difference between g (1981) and g (1985) was +17.1 ± 12.6, whereas on pillar A6 it was -0.4 ± 10.1 μgal. If we compare the correlation of g results on pillar A, it appears from the total of all measurements that gravity on pillar A during the intervening four years changed by 4.1 ± 5.9 μgal, a result completely consistent with no change at all having occurred. This result is in itself a bit surprising, for in this time frame a new laser laboratory was built at the BIPM immediately adjacent to the building in which pillar A is located. And though it is difficult to calculate exactly the effect of this new building's resulting "mass change" on the value of g at site A, a rough estimate would suggest that the value of g on pillar A — were nothing else to have changed in this four-year period — should be smaller by about 20 μgal, a number which is consistent with the (apparent) change that Sakuma has measured.

Conclusions

The Second International Comparison of Absolute Gravimeters involving six instruments from five different countries was carried out in Sevres during June-July of 1985. All of the instruments appeared to work very well. The results of this intercomparison are, however, somewhat more discordant than one would have expected in view of the assigned 6-12 μgal error associated with the various instruments. Further, the apparent measurement discordance between the BIPM instrument of Sakuma and the other instruments is both surprising and unresolved. Transfer errors — even were the estimated error of the relative measurements to be increased by a factor of 3 to allow for some possible systematic error source affecting all of the instruments — cannot explain this discrepancy. The desireability of making measurments,

however, with the same absolute apparatus at each of these sites is apparent. The intercomparison has served (again) to alert the various participants to the possibility that systematic errors may still be associated with their instruments. Accordingly, it has made clear the need for continued testing of the individual instruments in their home laboratories. Finally, it has pointed to the value of and the probable need for a Third International Comparison of Absolute Gravimeters in some 3-5 years.

Acknowlegements

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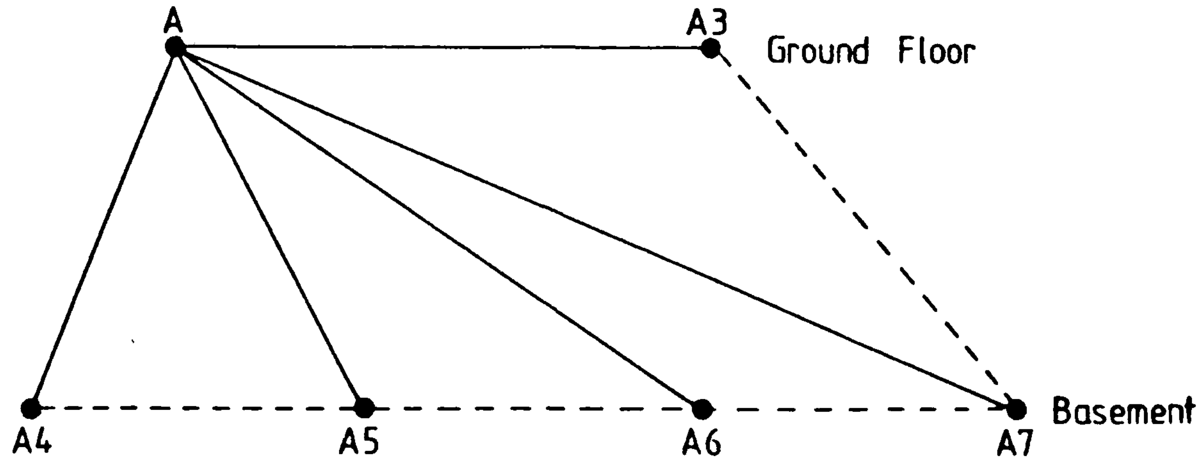
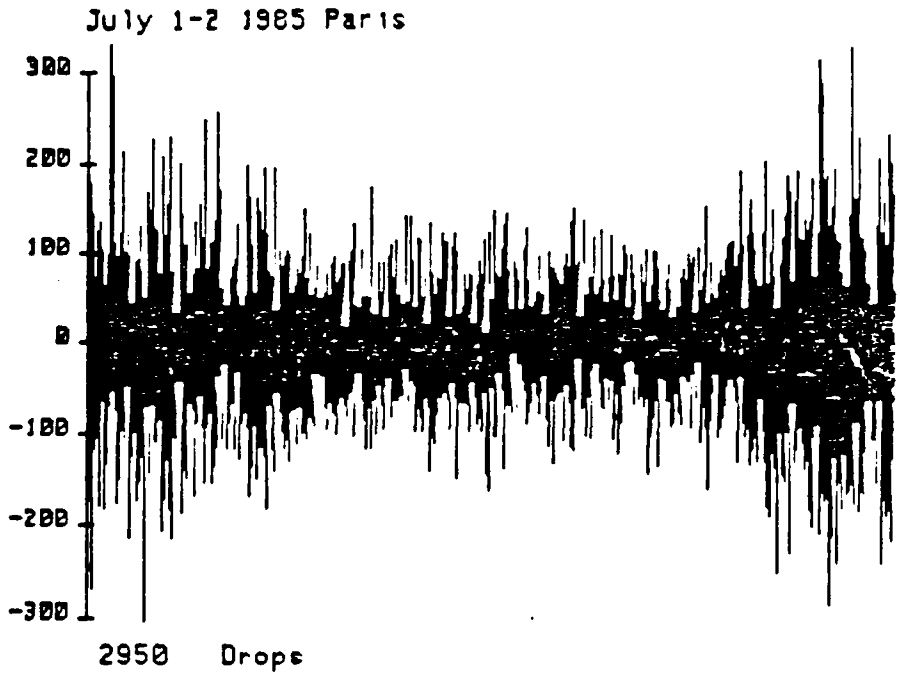


Fig.1 Micro gravity net, Sèvres 1985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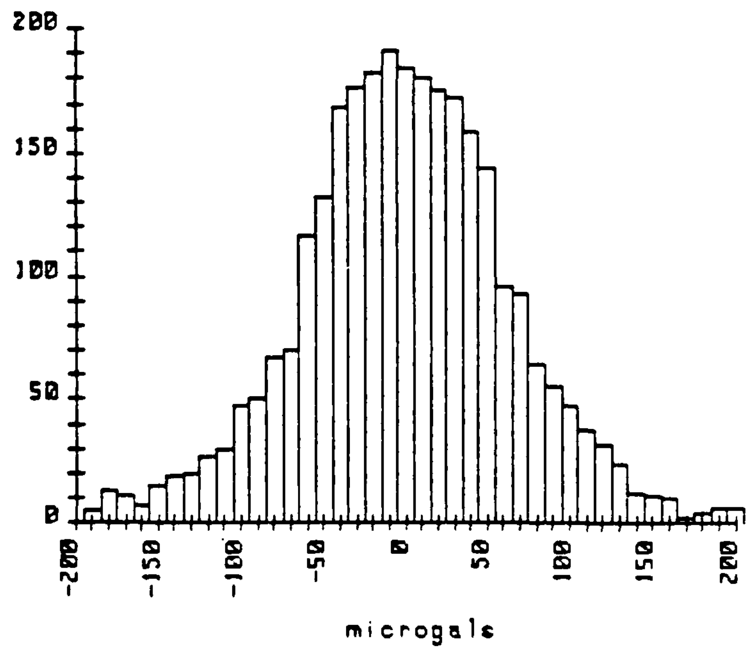
2950 Drops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100
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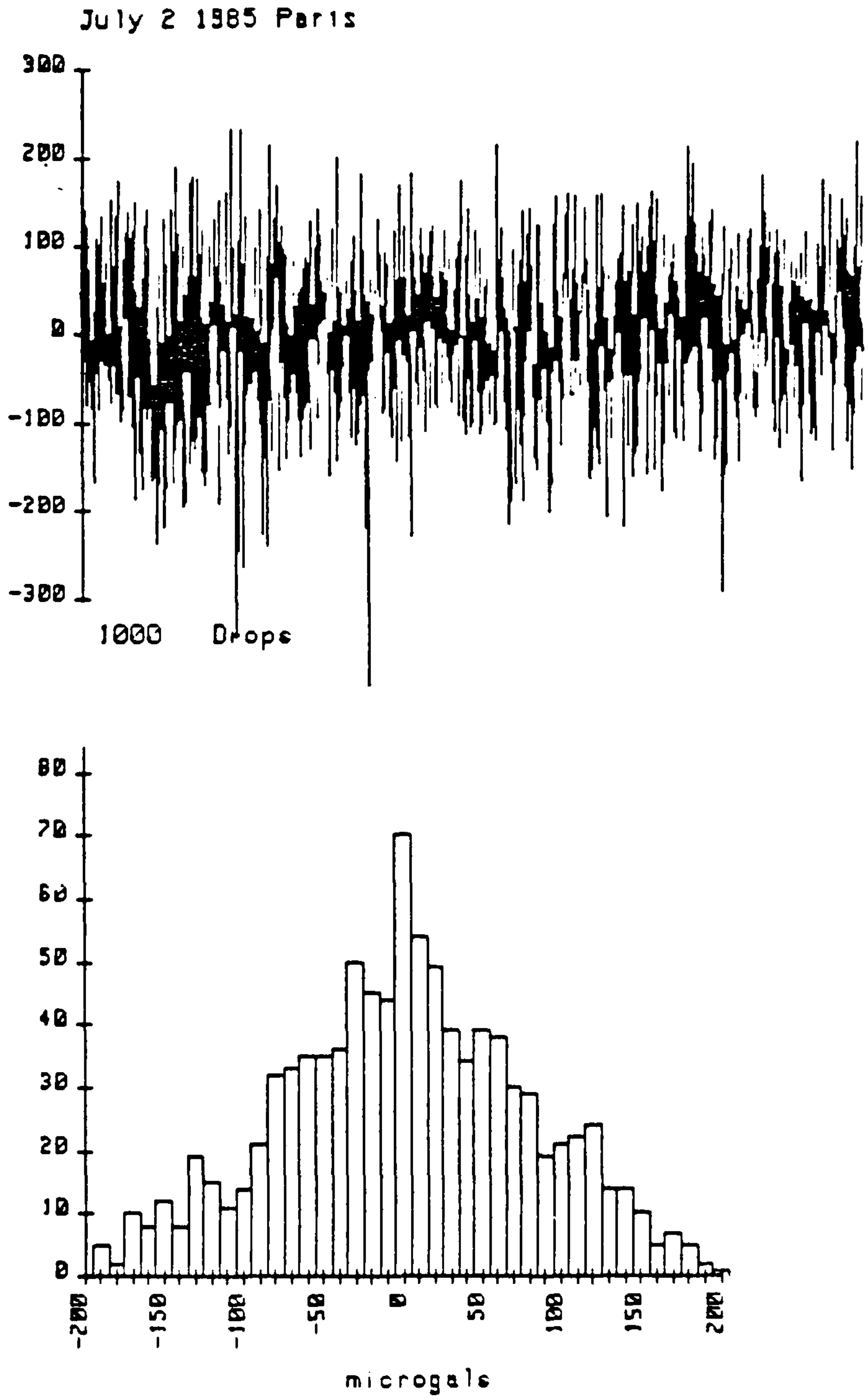
microgals

Fig. 2


July 2 1985 Paris
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200
100
0
-100
-200
-300
1000 Drops
80
70
60
50
40
30
20
10
0
-200
-150
-100
-50
0
50
100
150
200
microgals

Fig. 3

Gradient-Measurements Sèvres A

	Instr.	Instrumental height down	up	Difference m	Number of obs.	Gradient μgal/m
1	D8F	0.212	1.212	1	11	312.5±0.4
2	G298F	0.214	1.214	1	13	313.7±1.3
3	G709F	0.208	1.208	1	11	311.1±0.7
4	G563	0.406	1.406	1	8	313.7±0.9
5	D21	0.186	1.185	0.999	6	309.7±0.1
6	G54	0.217	1.031	0.814	6	314.3±0.9
7	G290	0.212	1.027	0.815	8	-
8	G305	-	-	1	6	308.2±4.6
9	G258	0.229	1.227	0.998	8	312.0±1.4
10	D38F	0.234	1.232	0.998	9	313.5±1.7
11	G131	0.206	1.206	1	7	303.3±1.3
12	D79	0.208	1.208	1	8	311.4±4.6
	Mean					311.4±0.7

Table 1.1

Gradients Sèvres A 3

	Instr.	Instrumental height down	up	Difference m	Number of obs.	Gradient μgal/m
1	D8F	0.212	1.212	1	15	296.0±0.5
					13	296.4±1.2
2	G298F	0.214	1.214	1	11	290.0±0.7
					11	291.3±1.0
3	G709F	0.208	1.208	1	13	296.8±1.6
					11	297.0±0.7
4	G563	0.406	1.406	1	8	292.1±0.9
5	D21	0.192	1.191	0.999	6	291.5±0.5
6	G54	0.216	1.035	0.819	6	295.7±1.3
7	G290	0.212	1.032	0.820	8	303.9±0.5
8	G305	-	-	1	6	300.4±1.3
9	G258	0.229	1.229	1	8	299.4±3.3
10	D38F	0.234	1.234	1	9	302.3±1.0
11	G131	0.206	1.206	1	7	290.1±1.0
12	D79	0.208	1.208	1	7	298.7±2.1
	Mean					295.2±1.1

Table 1.2

Gradients S è v r e s A 4

	Instr.	Instrumental height down	up	Difference m	Number of obs.	Gradient µgal/m
1	D8F	0.212	1.212	1	12	257.4±1.1
					11	254.4±1.5
2	G298F	0.214	1.214	1	11	255.0±1.2
3	G709F	0.208	1.208	1	13	252.0±1.4
					11	255.0±0.7
4	G563	0.406	1.406	0.999	6	253.9±1.2
5	D21	0.190	1.190	1	6	254.7±0.1
6	G54	0.219	1.036	0.817	6	261.1±0.6
7	G290	0.214	1.031	0.817	8	261.8±0.7
8	G305	-	-	1	6	246.5±0.8
9	G258	0.229	1.229	1	8	256.7±2.5
10	D38F	0.234	1.234	1	8	259.9±1.5
11	G131	0.206	1.206	1	7	262.3±0.7
12	D79	0.208	1.208	1	7	258.2±4.5
	Mean					255.9±1.0

Table 1.3

Gradients S è v r e s A 5

	Instr.	Instrumental height down	up	Difference m	Number of obs.	Gradient µgal/m
1	D8F	0.212	1.212	1	13	251.8±0.5
2	G298F	0.214	1.214	1	11	256.4±0.8
					11	253.5±0.9
3	G709F	0.208	1.208	1	11	251.3±0.5
4	G563	0.406	1.406	1	6	252.5±1.0
5	D21	0.191	1.190	0.999	6	251.4±0.3
6	G54	0.218	1.035	0.817	6	253.4±0.3
7	G290	0.213	1.031	0.818	9	254.3±1.0
8	G305	-	-	1	6	245.5±1.0
9	G258	0.229	1.229	1	8	255.8±1.5
10	D38F	0.234	1.234	1	8	250.1±1.7
11	G131	0.206	1.206	1	7	255.4±0.9
12	D79	0.208	1.208	1	7	256.8±4.2
	Mean					252.5±0.7

Table 1.4

Gradients Sèvres A 6

	Instr.	Instrumental height down	up	Difference m	Number of obs.	Gradient μgal/m
1	D8F	0.212	1.212	1	14	259.6±1.0
					11	257.4±1.0
2	G298F	0.214	1.214	1	11	257.3±1.0
3	G709F	0.208	1.208	1	11	257.4±0.5
4	G563	0.190	1.189	0.999	6	256.6±1.4
5	D21	0.190	1.189	0.999	6	257.9±0.4
6	G54	0.217	1.036	0.819	8	261.3±1.4
7	G290	0.213	1.033	0.820	8	260.1±0.9
8	G305	-	-	1	6	253.2±0.7
9	G258	0.229	1.229	1	8	267.4±1.3
10	D38F	0.234	1.234	1	8	264.0±1.0
11	G131	0.206	1.206	1	7	262.5±1.4
12	D79	0.208	1.208	1	6	259.9±0.9
	Mean					259.0±0.8

Table 1.5

Gradients Sèvres A 7

	Instr.	Instrumental height down	up	Difference m	Number of obs.	Gradient μgal/m
1	D8F	0.212	1.212	1	11	257.8±0.7
					11	260.2±0.7
2	G298F	0.214	1.214	1	11	256.2±0.9
3	G709F	0.208	1.208	1	11	258.8±0.8
					10	258.0±1.1
4	G563	0.407	1.406	0.999	6	254.7±0.7
5	D21	0.192	1.191	0.999	6	258.7±0.3
6	G54	0.218	1.036	0.818	6	263.8±1.5
7	G290	0.214	1.032	0.818	8	261.2±0.8
8	G305	-	-	1	6	260.4±0.7
9	G258	0.229	1.229	1	10	262.0±2.0
10	D38F	0.234	1.234	1	10	260.5±1.0
					8	259.7±0.6
11	G131	0.206	1.206	1	7	262.5±0.5
12	D79	0.208	1.208	1	6	256.8±3.3
	Mean					259.1±0.5

Table 1.6

Table 2. G-values of free-net single and combined adjustments with relative gravimeters only (μgal).

Instr.	1		3		4		5		6		7		
	g	mg	g	mg	g	mg	g	mg	g	mg	g	mg	$\overline{mg}$
D8F	+0.05	1.32	-67.85	1.15	+583.75	1.93	+577.85	0.91	+608.85	1.34	+657.85	1.12	1.3
G298F	-0.72	1.0	-72.02	1.10	+584.18	1.37	+579.88	1.02	+609.48	1.22	+659.68	1.13	1.1
G709F	-0.45	0.62	-67.65	0.61	+582.85	0.50	+577.45	0.48	+610.05	0.58	+658.25	0.57	0.6
G563	+4.28	1.26	-67.52	1.32	+581.78	1.54	+575.98	1.36	+606.88	1.32	+659.08	1.24	1.3
D21	-1.45	0.25	-69.45	0.33	+583.55	0.34	+579.35	0.26	+609.75	0.35	+661.65	0.32	0.3
G54	-0.65	1.09	-70.05	1.08	+582.05	1.36	+576.95	1.11	+610.75	1.13	+661.45	1.17	1.2
G290	-1.45	1.24	-74.55	1.24	+584.25	1.59	+579.25	1.25	+610.05	1.24	+662.95	1.36	1.3
G305	+4.22	2.86	-64.38	3.19	+578.62	4.90	+580.12	2.73	+607.42	2.86	+654.52	2.67	3.3
G258	-3.88	1.58	-75.88	1.42	+589.82	2.73	+579.52	1.75	+607.82	2.07	+663.12	1.55	1.9
D38F	-1.32	1.89	-77.52	1.62	+587.48	1.52	+580.18	1.71	+612.68	1.62	+658.98	1.62	1.7
G131	-2.55	0.80	-71.05	0.78	+584.95	0.86	+579.45	0.72	+610.45	0.75	+659.25	0.80	0.8
D79	-0.57	2.14	-70.77	1.98	+582.83	2.22	+580.83	2.26	+607.73	1.89	+660.43	2.30	2.1
D31F	+0.47	2.92	-74.53	3.01	+588.37	2.96	+580.77	2.58	+607.87	4.95	+657.57	2.60	3.2
G487F	+0.12	1.02	-73.58	1.10	+585.32	1.09	+581.62	1.04	+611.42	1.21	+655.62	1.00	1.1
comb.	0.0	0.4	-70.7	0.4	583.2	0.5	578.7	0.4	609.2	0.4	660.1	0.4	0.4

Source	Sakuma	Becker, Groten	B.R.G.M. (Ogier)	Becker	B.R.G.M. (Ogier)
year	1980	1981	1984	1985	1985
W_{zz}	273	283.6±1.6	274.8	295.2±1.1	296.9±4.6

Table 1a

tie	1981	1981 corrected	1985	Diff
A -A3	-79.6	- 69.6	-70.7	- 1.0
A3-A4	657.4	647.4	653.9	+ 6.5
A3-A5	659.2	649.2	649.4	+ 0.2
A3-A6	686.4	676.4	679.9	+ 3.5
A4-A5	1.8	-	-4.5	- 6.3
A4-A6	29.0	-	26.0	- 3.0
A5-A6	27.2	-	30.5	- 3.3

Table 2a

Table 3

Errors of Measurements

Source of errors	France A	Italy A3	USSR A3	China A4	USA A5	USSR A6	USA A7
			m c g a l				
Error of one drop	-	± 13	± 130	± 283	-	± 144	± 175
Number of drops	300	112	900	292	3950	1651	2571
Acciesental errors	± 5.6	± 2.2	± 3.2	± 11.2	± 2.0	± 4.0	± 3.6
Lascr wavelength	-	2	2	4	2	2	2
Magnetic forces effect	-	-	1	3	-	1	1
Electrostatic effect	-	-	-	-	-	-	1
Pressure effect	-	3	3	6	5	3	2
Optical effects	-	-	2	-	-	2	3
Time interval determination	-	1	1	-	-	-	1
Deviation from vertical	-	2	-	-	-	-	2
Body rotation	-	2	-	-	-	-	1
Frequency non-stability	-	-	1	-	-	1	1
Temoerature effect	-	-	-	-	-	-	2
Responce effect	-	-	-	-	5	-	1
Translation	-	-	-	2	-	-	1
Reduction to pillar surface	0.7	1.1	1.1	1.0	0.7	0.8	0.5
Total errors M	± 5.6	± 5.3	± 5.6	±13.8	± 8.0	± 6.0	± 6.7

Table 4

Results of absolute gravity measurements

Country	Points	H_o	W_{zz}	g $(H - H_o)$	Δg_H	g $(H = 0)$	M
		mm	mcgal	mcgal	mcgal	mcgal	mcgal
1. France	A	1120	311.4	980 925 627.5	348.8	980 925 976.3	± 5.6
2. Italy	A3	851	295.2	673.4	251.2	924.7	5.3
3. USSR	A3	980	295.2	642.5	289.3	931.8	5.6
4. China	A4	1120	255.9	926 313	286.6	926 599.6	13.8
5. USA	A5	830	252.5	368.5	209.6	578.1	7.8
6. USSR	A6	971	259.0	359.7	251.5	611.2	6.0
7. USA	A7	1090	259.1	391.1	282.4	673.5	6.7

Table 5

Results of comparison absolute gravimeters

Country	Points	g		Reductions		g(A)		$\overline{g}$(A)
		mcgal		mcgal		mcgal		mcgal
BIPM	A	980 925 976.3 ±	5.6	-		980 925 976.3 ±	5.6	980 925 976.3 ± 5.6
Italy	A3	925 924.7	5.3	+ 70.7 ±	0.4	925 995.4	5.3	
USA 1	A5	926 578.1	7.6	- 578.7	0.4	925 999.4	7.6	980 925 999.8 ± 3.1
USSR	A3	925 931.8	5.6	+ 70.7	0.4	926 002.5	5.6	
USSR	A6	926 611.2	6.0	- 609.2	0.4	926 002.0	6.0	
USA 2	A7	926 673.5	6.7	- 660.1	0.4	926 013.4	6.7	980 926 014.8 ± 7.6
China	A4	926 599.4	13.8	- 583.2	0.5	926 016.2	13.8	

Average simpl of all results: $\overline{g}$ = 980 926 000.7

m = ± 13.2

M = ± 5.0

Average weighed of all results: $\overline{g}$ = 980 925 997.7

M = ± 4.4

Table 6

Changes of gravity field

Year	g	W_{zz}	Δg	g(A)
	mcgal	mcgal	mcgal	mcgal
		Point A5 (USA, J.Faller)		
1981	980 926 562 ± 10	250.0 ± 1.1	- 579.6 ± 1.2	980 925 982.4 ± 10.1
1985	578.1 7.8	252.5 ± 0.7	- 578.7 ± 0.4	999.4 7.8
Diff.	+ 16.1 ± 12.7	+ 2.5 ± 1.3	+ 0.9 ± 1.3	+ 17.0 ± 12.8
		Point A6 (USSR, G.Arnautov)		
1981	980 926 609 ± 8	251.8 ± 1.2	- 606.8 ± 1.4	980 926 002.2 ± 8.1
1985	611.2 ± 6.0	259.0 ± 0.8	- 609.2 ± 0.4	002.0 ± 6.0
Diff.	+ 2.2 ± 10.0	+ 7.2 ± 1.4	- 2.4 ± 1.5	- 0.2 ± 10.1
		Point A3 (All measurements)		
1981	980 925 914 ± 3.7	(283.6±1.6)	+ 79.6 ± 1.5	980 925 993.6 ± 4.0
1985	928.2 ± 4.4	(295.2±1.1)	+ 70.7 ± 0.4	998.9 ± 4.4
Diff.	+ 14.2 ± 5.7	(+11.6±1.9)	- 8.9 ± 1.6	+ 5.3 ± 5.9

Appendix 1

Results of measurements at point A3, Sevres, 1985

Observers: L.Cannizzo, G.Cerutti, I.Marson; Instituto di Metrologia "G.Colonnetti", Italy

W_{zz} = 295.5 mcgal/m

No	Time (UT)	H_o	Measured g	ε	P_a	ε_{P_a}	ε
		mm	mcgal	mcgal	mbar	mcgal	mcgal
			Serie n 1		June 30		
1	13h35m	856.9	980 925 620.0	57.4	1009.7	- 1.4	980 925 929.2
2	13 40	865.8	604.6	53.6	9.7	- 1.4	912.6
3	13 51	863.1	602.2	45.2	9.6	- 1.5	900.9
4	13 56	862.0	613.0	41.4	9.6	- 1.5	907.6
5	14 03	854.5	637.6	36.1	9.5	- 1.5	924.7
6	14 08	854.6	641.1	32.3	9.5	- 1.5	924.4
7	14 14	860.3	642.7	27.7	9.4	- 1.5	923.1
8	14 18	861.2	663.2	24.6	9.4	- 1.5	940.8
9	14 23	860.2	657.9	20.6	9.4	- 1.5	931.1
10	14 28	853.3	679.6	16.9	9.3	- 1.6	947.1
11	14 34	860.3	663.5	12.4	9.3	- 1.6	928.5
12	15 16	851.4	694.0	-18.0	9.1	- 1.7	925.9
13	15 21	861.9	683.3	-21.5	9.1	- 1.7	914.8
14	15 26	860.3	692.4	-25.0	9.0	- 1.7	919.9
15	15 31	851.4	701.3	-28.4	9.0	- 1.7	922.4
16	15 36	858.4	720.5	-31.5	9.0	- 1.7	941.0
17	15 41	857.7	712.3	-34.7	8.9	- 1.8	929.3
18	15 50	851.3	712.1	-40.2	8.9	- 1.8	921.7
19	15 55	858.9	730.9	-43.4	8.8	- 1.8	939.5
20	16 00	858.0	724.7	-46.5	8.8	- 1.8	929.9
21	16 05	856.6	726.9	-49.1	8.8	- 1.8	929.1
22	16 10	856.6	734.4	-51.8	8.7	- 1.8	933.9
23	16 16	855.7	740.5	-54.9	8.7	- 1.8	936.7
24	16 22	848.0	737.5	-58.1	8.7	- 1.8	923.2
25	16 27	848.3	725.0	-60.7	8.6	- 1.9	913.1
26	16 33	849.0	741.9	-63.1	8.6	- 1.9	927.8
27	16 38	856.1	742.1	-65.9	8.6	- 1.9	927.3
28	16 44	847.0	750.2	-68.2	8.5	- 1.9	930.4
29	16 49	847.2	751.8	-70.3	8.5	- 1.9	929.9
30	16 54	854.8	756.1	-72.5	8.4	- 2.0	934.2

Continuation

		mm	mcgal	mcgal	mbar	mcgal	mcgal
31	16^h59^m	848.3	980 925 749.8	-74.6	1008.4	- 2.0	980 925 923.9
32	17 04	854.6	746.9	-76.3	8.2	- 2.1	921.0
33	17 09	854.1	756.4	-77.8	8.2	- 2.1	928.9
34	17 16	854.3	753.0	-79.7	8.2	- 2.1	923.6
35	17 20	854.0	764.1	-81.3	8.2	- 2.1	933.1
36	17 25	854.7	772.8	-82.8	8.2	- 2.1	940.5

k = 36; $\bar{H}_o$ = 855.6 mm

$\bar{g}$ = 980 925 927.1

m = ± 9.6 mcgal

M_o = ± 1.6 mcgal

Serie n.2 **July 01**

1	08 30	846.6	980 925 584.4	91.0	1008.5	- 1.9	980 925 923.7
2	08 36	846.1	586.5	95.1	8.5	- 1.9	929.7
3	08 42	846.7	578.0	99.1	8.5	- 1.9	925.4
4	08 46	845.1	586.4	101.8	8.5	- 1.9	936.0
5	08 49	845.1	592.1	103.9	8.5	- 1.9	943.8
6	08 53	852.6	543.8	106.6	8.5	- 1.9	900.4
7	08 56	852.6	599.5	108.6	8.5	- 1.9	959.1
8	09 00	846.0	559.6	111.3	8.5	- 1.9	919.0
9	09 03	853.0	554.8	113.0	8.5	- 1.9	918.0
10	09 07	854.8	570.0	115.3	8.5	- 1.9	936.0
11	09 11	845.3	573.2	117.6	8.5	- 1.9	938.7
12	09 15	844.6	567.8	119.9	8.5	- 1.9	935.4
13	09 20	851.9	525.9	122.8	8.5	- 1.9	898.5
14	09 25	845.4	558.6	125.1	8.6	- 1.9	931.6
15	09 32	851.0	577.7	129.4	8.6	- 1.9	956.7
16	09 36	843.6	551.3	131.2	8.6	- 1.9	929.9
17	09 40	851.1	541.2	132.9	8.6	- 1.9	923.7
18	09 44	843.1	545.3	134.7	8.6	- 1.9	927.2
19	09 47	851.0	525.0	136.0	8.6	- 1.9	910.6
20	09 50	843.6	547.6	137.4	8.6	- 1.9	932.4
21	09 53	851.0	531.2	138.7	8.6	- 1.9	919.5
22	09 59	850.3	519.0	141.4	8.6	- 1.9	909.8
23	10 02	842.9	549.7	142.4	8.6	- 1.9	939.3
24	10 06	842.9	532.7	143.5	8.6	- 1.9	923.4
25	11 09	850.4	547.2	144.4	8.6	- 1.9	941.0

Continuation

		mm	mcgal	mcgal	mbar	mcgal	mcgal
26	10^h12^m	851.3	980 925 517.4	145.3	1008.6	- 1.9	980 925 912.4
27	10 16	842.6	523.9	146.4	8.6	- 1.9	917.4
28	10 19	850.1	510.8	147.3	8.6	- 1.9	907.4
29	10 22	842.9	538.3	148.2	8.6	- 1.9	933.7
30	10 26	850.7	526.7	149.3	8.6	- 1.9	925.5
31	10 29	851.5	552.1	150.2	8.6	- 1.9	951.7
32	10 33	851.5	522.5	150.9	8.6	- 1.9	923.1
33	10 36	842.4	519.2	151.3	8.6	- 1.9	917.5
34	10 39	842.3	527.8	151.6	8.6	- 1.9	926.4
35	10 43	843.9	523.1	152.0	8.6	- 1.9	922.6
36	10 46	850.4	549.6	152.5	8.7	- 1.8	951.6
37	10 49	850.3	532.5	152.9	8.7	- 1.8	934.9
38	10 52	850.0	509.8	153.3	8.7	- 1.8	912.5
39	10 56	850.3	510.6	153.8	8.7	- 1.8	913.9
40	11 00	851.3	536.7	154.3	8.7	- 1.8	940.8
41	11 03	842.4	517.5	154.2	8.7	- 1.8	918.8
42	11 06	842.3	530.8	154.0	8.7	- 1.8	931.9
43	11 10	843.9	510.6	153.9	8.7	- 1.8	912.1

$k = 43$; $\bar{H}_o = 847.6$ mm

$\bar{g} = 980\ 925\ 927.0$

$m = \pm 14.0$ mcgal

$M_o = \pm 2.2$ mcgal

Serie n.3 July 01

1	13 19	845.7	980 925 566.1	108.0	1008.8	- 1.8	980 925 922.2
2	13 22	853.9	558.8	106.1	8.9	- 1.8	915.4
3	13 30	845.6	563.3	101.7	8.9	- 1.8	913.1
4	13 55	843.4	619.2	83.0	8.9	- 1.8	949.6
5	13 58	845.8	601.6	80.8	8.9	- 1.8	930.5
6	14 02	852.5	623.7	77.8	8.9	- 1.8	951.6
7	14 06	853.7	588.0	74.7	8.9	- 1.8	913.2
8	15 41	848.4	683.4	- 0.4	9.1	- 1.7	932.0
9	15 46	848.4	691.6	- 3.8	9.1	- 1.7	936.8
10	15 50	856.0	704.9	- 6.5	9.1	- 1.7	949.6
11	15 54	854.9	671.4	-10.3	9.1	- 1.7	912.0
12	15 57	849.0	683.6	-12.5	9.1	- 1.7	920.3
13	16 00	856.2	696.1	-14.8	9.1	- 1.7	932.6
14	16 04	856.7	664.2	-17.6	9.1	- 1.7	898.1

Continuation

		mm	mcgal	mcgal	mbar	mcgal	mcgal
15	16 08	848.3	980 925 684.7	-20.3	1009.1	- 1.7	980 925 912.4
16	16 22	851.1	685.3	-30.1	9.1	- 1.7	905.0
17	16 26	857.7	720.0	-32.1	9.1	- 1.7	939.7
18	16 29	856.7	686.3	-34.9	9.1	- 1.7	902.9
19	16 32	856.5	725.9	-36.8	9.1	- 1.7	940.5
20	16 35	855.9	701.0	-38.6	9.1	- 1.7	913.6
21	16 39	856.4	710.4	-40.4	9.1	- 1.7	921.4
22	16 42	855.1	711.4	-42.8	9.1	- 1.7	919.6
23	16 45	848.2	715.4	-44.6	9.1	- 1.7	919.7
24	16 48	847.2	702.6	-46.5	9.1	- 1.7	904.7
25	16 54	855.5	723.5	-50.1	9.2	- 1.6	924.6
26	16 58	847.7	717.9	-52.5	9.2	- 1.6	914.3
27	17 01	846.7	721.6	-54.2	9.2	- 1.6	916.0
28	17 04	847.1	702.6	-55.7	9.2	- 1.6	895.6
29	17 07	847.8	703.7	-58.5	9.2	- 1.6	894.1
30	17 13	845.7	717.1	-60.2	9.2	- 1.6	905.2
31	17 17	845.6	732.2	-62.1	9.2	- 1.6	918.4
32	17 21	846.8	743.8	-63.6	9.2	- 1.6	928.8
33	17 24	853.0	742.1	-65.6	9.2	- 1.6	927.0

k = 33 $\bar{H}_o$ = 850.9

$\bar{g}$ = 980 925 920.7
m = ± 15.2 mcgal
M_o = ± 2.7 mcgal

Serie n.1	g = 980 925 927.1	m = ± 9.6	M_o = ± 1.6
Serie n.2	927.0	14.0	2.1
Serie n.3	920.7	15.2	2.7
Average:	g = 980 925 924.9	m = ± 13.2	M_o = ± 2.2

Appendix 2

Results of measurements at point A3, Sevres, 1985

Observer: G.Arnautov (USSR) $H_o = 0.980$ m $W_{zz} = 295.5$ mcgal/m

Set No	Date	Time (UT)	Measured g Value	k	m	P_a	Corrections Δg_p	Corrections Δg	Corrections g_{P_a}	g
			mcgal			mbar	mcgal			mcgal
1	July 08	$21^h59^m - 22^h16^m$	980 925 731	90	± 16	1013	14	-70	0	980 925 941
2	08	22 35 22 50	726	90	13	1013	14	-73	0	933
3	08	23 00 23 18	716	90	14	1013	14	-73	0	923
4	july 09	1 19 1 33	710	90	12	1013	16	-51	0	941
5	09	1 43 1 58	711	90	14	1013	16	-45	0	948
6	09	2 06 2 23	677	90	14	1013	18	-39	0	922
7	09	2 33 2 47	681	90	13	1013	16	-32	0	931
8	09	3 09 3 24	677	90	14	1013	16	-23	0	936
9	09	3 30 3 48	651	90	15	1013	16	-18	0	915
10	09	3 56 4 13	661	90	13	1013	17	-13	0	931

Constant corrections:

$\Delta g_c = -24$ mcgal

$\Delta g_{H_0} = 289.6$ mcgal

$\sum k = 900$

$m = \pm 131$ mcgal

$\overline{m}_o = \pm 13.8$ mcgal

$\overline{g} = 980\ 925\ 932.1$

$m = \pm 10.0$ mcgal

$M_o = \pm 3.2$ mcgal

Appendix 3

Results of measurements at point A4, Sevres, 1985

Observers: Guo You-Gang, Huang Da-Lun, Feng Youg-Yuan, Zhang Guang-Yuan, Zhou Juing-Hua, National Institute of Metrology, China.

H_o = 1120 mm W_{zz} = 255.4 mcgal/m

Set	Date	Time (UT)	k	Measured g	m	g_{H_o}	g
				mcgal	mcgal	mcgal	
1	06 28	11^h-12^h	21	980 926 352	± 234	286	980 926 638
2	28	14 -16	20	392	210	286	678
3	06 29	8 - 9	20	282	189	286	568
4	29	12 -14	20	357	336	286	643
5	29	14 -16	25	316	274	286	602
6	06 30	8 -10	20	319	320	286	605
7	30	13 -15	20	317	264	286	603
8	30	15 -17	20	301	298	286	587
9	07 01	7 - 9	24	233	233	286	519
10	01	11 -13	21	347	264	286	633
11	01	17 -18	20	284	355	286	570
12	07 08	12 -13	20	323	398	286	609
13	08	14 -16	20	303	298	286	589
14	09	7 - 8	21	255	288	286	541

$\Sigma k = 292$ $\bar{m} = 283$ $\bar{g}$ = 980 926 599

m = ± 41.9

M_o = ± 11.2

Appendix 4

Results of measurements at point A6, Sevres, 1985

Observer: G.Arnautov (USSR) H_o = 0.971 m W_{zz} = 259.0 mcgal/m

Set No	Date	Time (UT)		Measured g Value	k	m	P_a	Corrections Δg_p	Corrections Δg_γ	Corrections Δg_{p_a}	g
				mcgal		mcgal	mbar	mcgal	mcgal	mcgal	mcgal
1	July 01	15^h28^m	$- 15^h47^m$	980 925 371	120	± 12	1013	+ 16	+ 2	0	980 926 616
2	01	15 55	16 14	387	120	12	1013	17	- 18	0	613
3	01	17 00	17 19	431	120	11	1013	20	- 58	0	620
4	01	17 50	18 10	453	120	11	1013	20	- 80	0	620
5	01	20 20	20 40	440	120	17	1013	15	- 91	0	591
6	01	20 50	21 10	428	120	17	1013	15	- 88	0	582
7	01	21 40	22 00	432	120	15	1013	14	- 81	0	592
8	01	22 10	22 30	447	120	16	1013	14	- 77	0	611
9	01	22 40	23 00	438	120	14	1013	14	- 75	0	604
10	01	23 45	24 05	469	120	11	1013	14	- 75	0	635
11	July 02	0 20	0 40	468	120	10	1013	14	- 78	0	631
12	02	0 50	1 10	462	120	13	1013	14	- 82	0	621
13	02	1 50	2 10	162	120	13	1013	14	- 90	0	613
14	02	2 20	2 35	461	91	12	1013	14	- 94	0	608

Constant corrections:

Δg_c = - 24 mcgal

Δg_{H_o} = +251 mcgal

$\sum k$ = 1651

m = ± 144 mcgal

$\bar{m}_o$ = ± 13.1 mcgal

$\bar{g}$ = 980 926 611.2

m = ± 15 mcgal

M_o = ± 4.0 mcgal

Appendix 5

Results of measurements at point A7, Sevres, 1985

Observers: M.Zumberge, C.Sasagawa, Scripps Institution of Oceanography, University of California, San Diego, La Jolla, California 92093, USA

H_0 = 1090 m W_{zz} = 259.0 mcgal/m

No		Time (UT)	Measured g Value	m	k	Corrections Finite c	Laser	Tide	g ($H = H_0$)
			mcgal			mcgal	mcgal	mcgal	mcgal
1	06 25	09^h32^m	980 926 439	± 181	99	- 10	- 3	- 25	980 926 401
2	25	11 48	427	173	100	- 10	- 3	- 27	397
3	25	12 12	437	157	99	- 10	- 3	- 25	399
4	25	12 48	411	208	100	- 10	- 3	- 20	378
5	25	13 12	421	195	99	- 10	- 3	- 16	392
6	25	13 49	421	224	100	- 10	- 3	- 8	400
7	25	14 22	399	161	99	- 10	- 3	- 2	384
8	25	14 52	398	189	99	- 10	- 3	+ 4	389
9	25	15 15	413	195	98	- 10	- 3	8	408
10	25	15 38	375	162	99	- 10	- 3	11	373
11	25	16 02	392	187	99	- 10	- 3	14	393
12	25	16 26	379	128	100	- 10	- 3	16	382
13	25	16 53	378	155	100	- 10	- 3	16	381
14	25	17 22	412	140	97	- 10	- 3	15	414
15	06 26	8 21	430	170	98	- 10	- 5	18	433
16	26	9 33	387	181	99	- 10	- 5	5	377
17	26	9 57	384	187	99	- 10	- 5	0	369

Continuation

18	06 26	10^h19^m	980 926 441	± 177	98	- 10	- 5	- 5	980 926 421
19	26	10 52	426	171	98	- 10	- 5	- 13	398
20	26	16 18	414	142	99	- 10	- 5	- 21	378
21	26	16 54	414	169	98	- 10	- 5	- 18	381
22	06 23	10 41	339	167	100	- 10	- 3	+ 69	395
23	28	11 14	398	175	99	- 10	- 3	55	440
24	28	12 18	404	191	97	- 10	- 3	21	412
25	28	12 41	401	190	98	- 10	- 3	9	397
26	28	13 03	387	186	100	- 10	- 3	- 3	371

$n = 26$

$\sum k = 2571$

$\bar{m} = \pm 175$ mcgal

$\bar{g} = 980\ 926\ 394.3$

$m = \pm 18.1$ mcgal

$M_o = \pm\ 3.6$ mcgal

Appendix 6 Review of relative measurements

Instrument	Date	A	A3	A4	A5	A6	A7	S
		Number of station occupations						
D8F	03.07.85	2	7	-	8	2	12	31
	04.07.85	2	3	1	2	2	1	11
	05.07.85	2	-	-	2	4	-	8
	06.07.85	7	10	5	11	3	2	38
G298F	03.07.85	9	8	-	8	4	5	34
	05.07.85	3	2	2	2	2	2	13
	06.07.85	6	6	7	9	2	5	35
G709F	03.07.85	8	9	-	6	5	11	39
	04.07.85	3	2	3	2	2	3	15
	06.07.85	6	6	12	12	5	4	45
G563	04.07.85	6	4	-	6	6	4	26
	05.07.85	2	2	2	2	2	3	13
	06.07.85	4	4	2	2	3	4	19
D21	03.07.85	3	3	-	2	2	2	12
	04.07.85	3	2	-	2	2	2	11
	06.07.85	3	-	6	3	-	-	12
G54	03.07.85	2	2	-	2	3	2	11
	04.07.85	2	2	2	3	2	2	13
	06.07.85	3	3	2	2	2	2	14
G290	03.07.85	2	2	-	2	3	2	11
	05.07.85	2	2	2	3	2	2	13
	06.07.85	3	3	2	2	2	2	13
G305	03.07.85	2	2	-	2	2	3	11
	04.07.85	2	2	3	2	2	2	13
G258	03.07.85	2	2	-	2	2	2	10
	04.07.85	2	2	3	2	2	2	13
	06.07.85	2	3	2	2	2	3	14
D38F	04.07.85	2	2	3	2	2	2	13
	05.07.85	2	2	3	2	2	2	13
G131	03.07.85	2	4	-	2	2	2	12
	05.07.85	2	4	2	2	.2	2	14
	06.07.85	2	2	2	3	4	2	15
D79	03.07.85	3	2	-	2	1	2	10
	05.07.85	2	3	2	2	4	2	15
	06.07.85	3	3	3	2	2	2	15
D31F	03.07.85	-	-	-	1	2	1	4
	06.07.85	2	3	2	2	-	2	11
	07.07.85	2	2	2	2	-	2	10
G487F	04.07.85	4	3	-	2	1	2	12
	05.07.85	2	2	2	2	2	3	13
	06.07.85	2	2	2	3	1	2	12

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